Mercury Target Tests: Proton Induced Shocks and MHD

A.Fabich, J.Lettry

http://cern.ch/afabich/docs.html

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- MHD:
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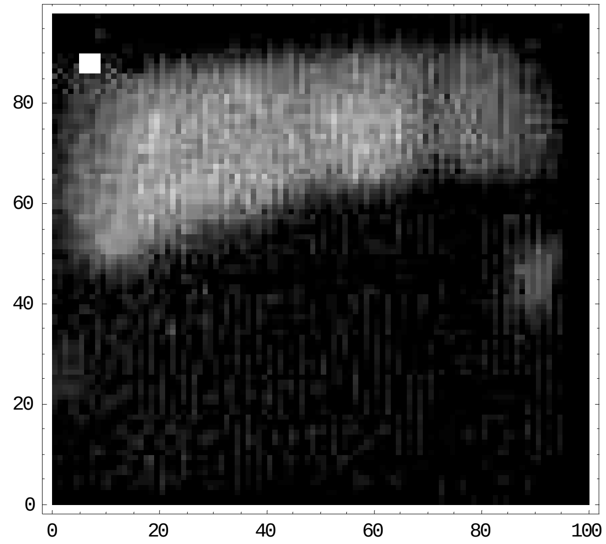


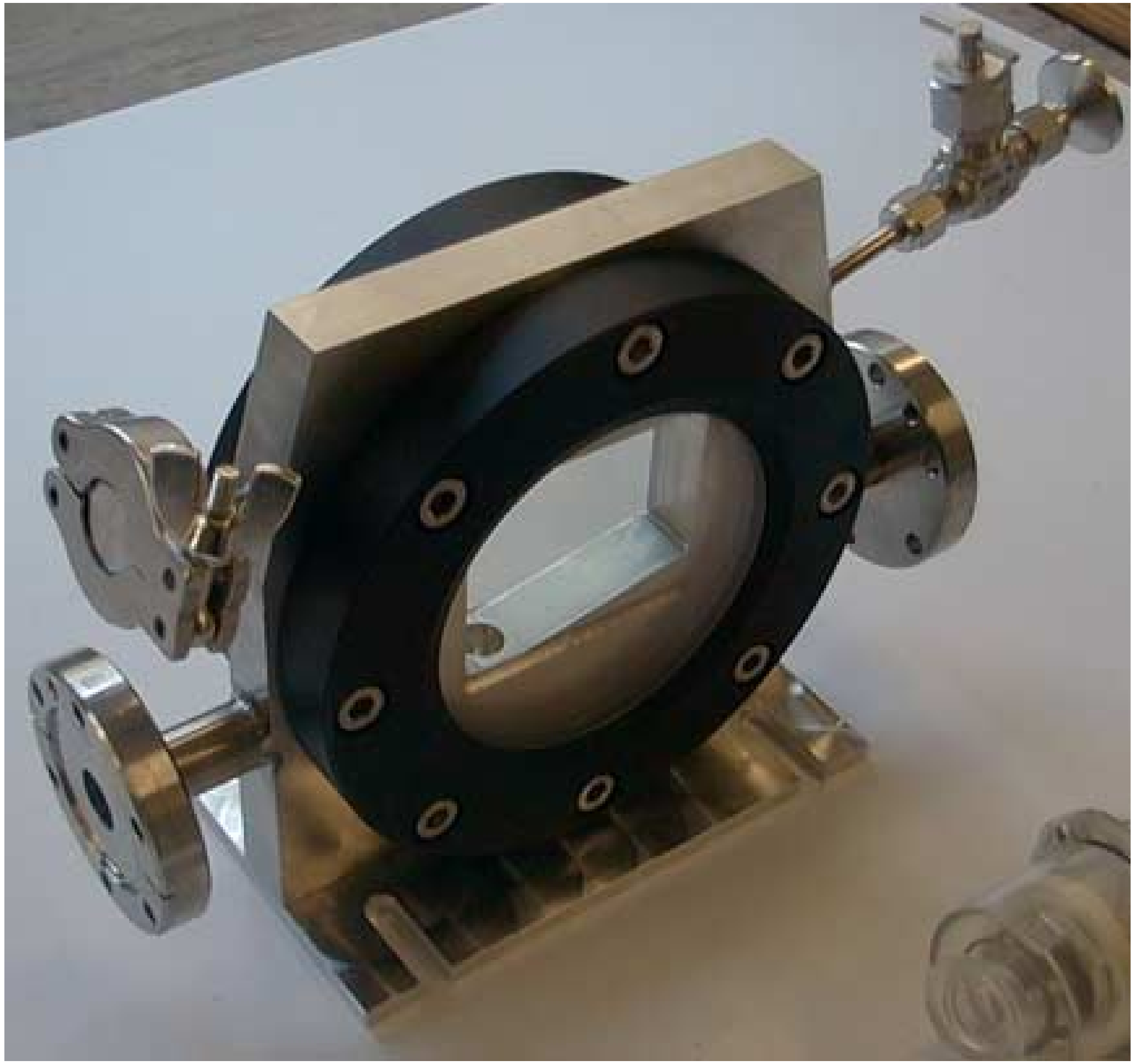
GOAL

feasibility of a liquid metal option for high power proton beam targets

- Proton induced shocks:
  - surface velocities
  - scaling laws
  - impact of cavitation voids on particle production
- MHD
  - Pinching
  - Deflection

THIMBLE

- ISOLDE GPS
- steel frame
  - with thimble/trough
  - viewing windows
- optical read-out by high-speed camera
  - 4000 frames/s
  - Shutter 12.5 μs



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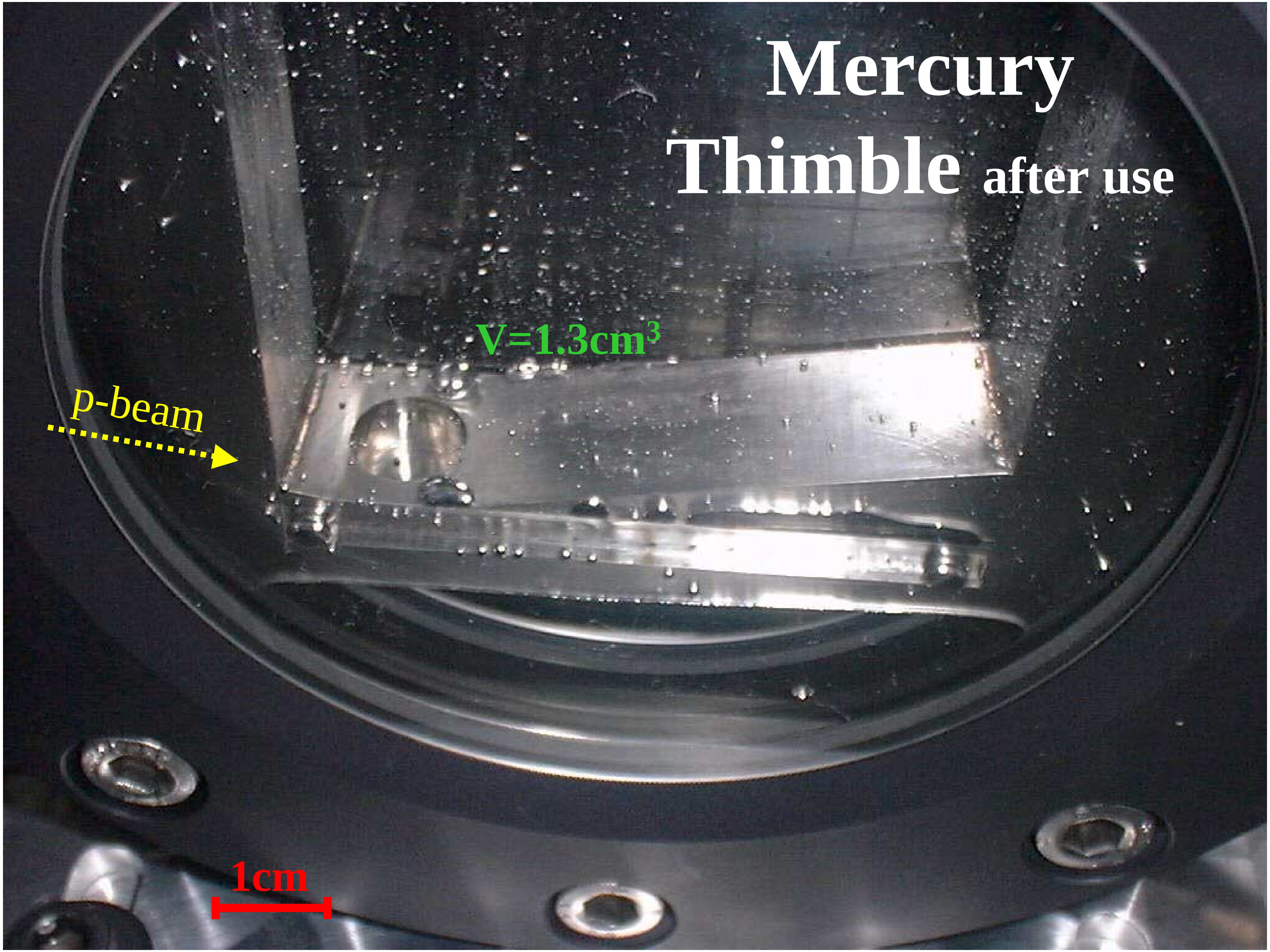
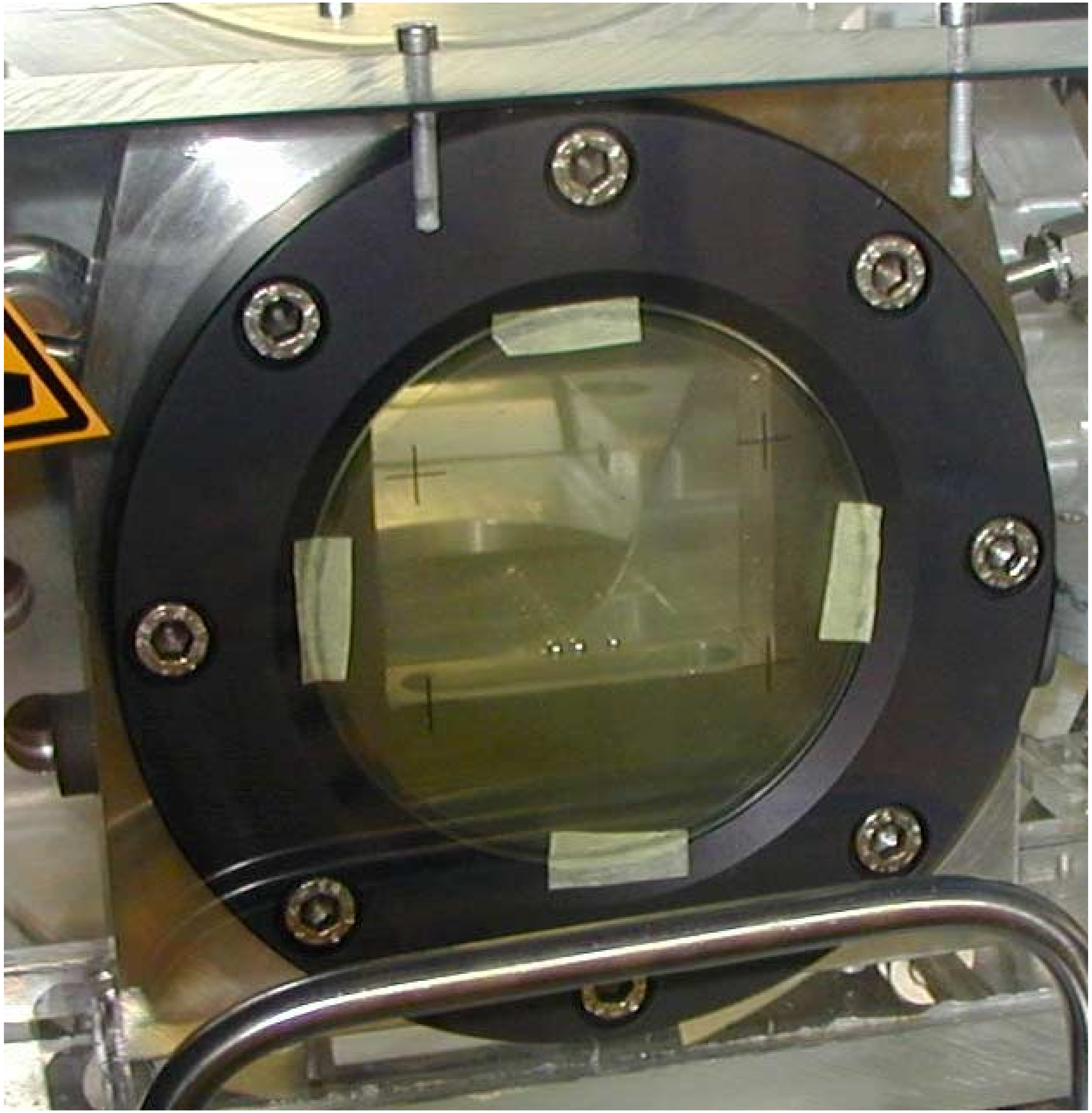

Mercury
Thimble after use
V=1.3cm3
p-beam
1cm

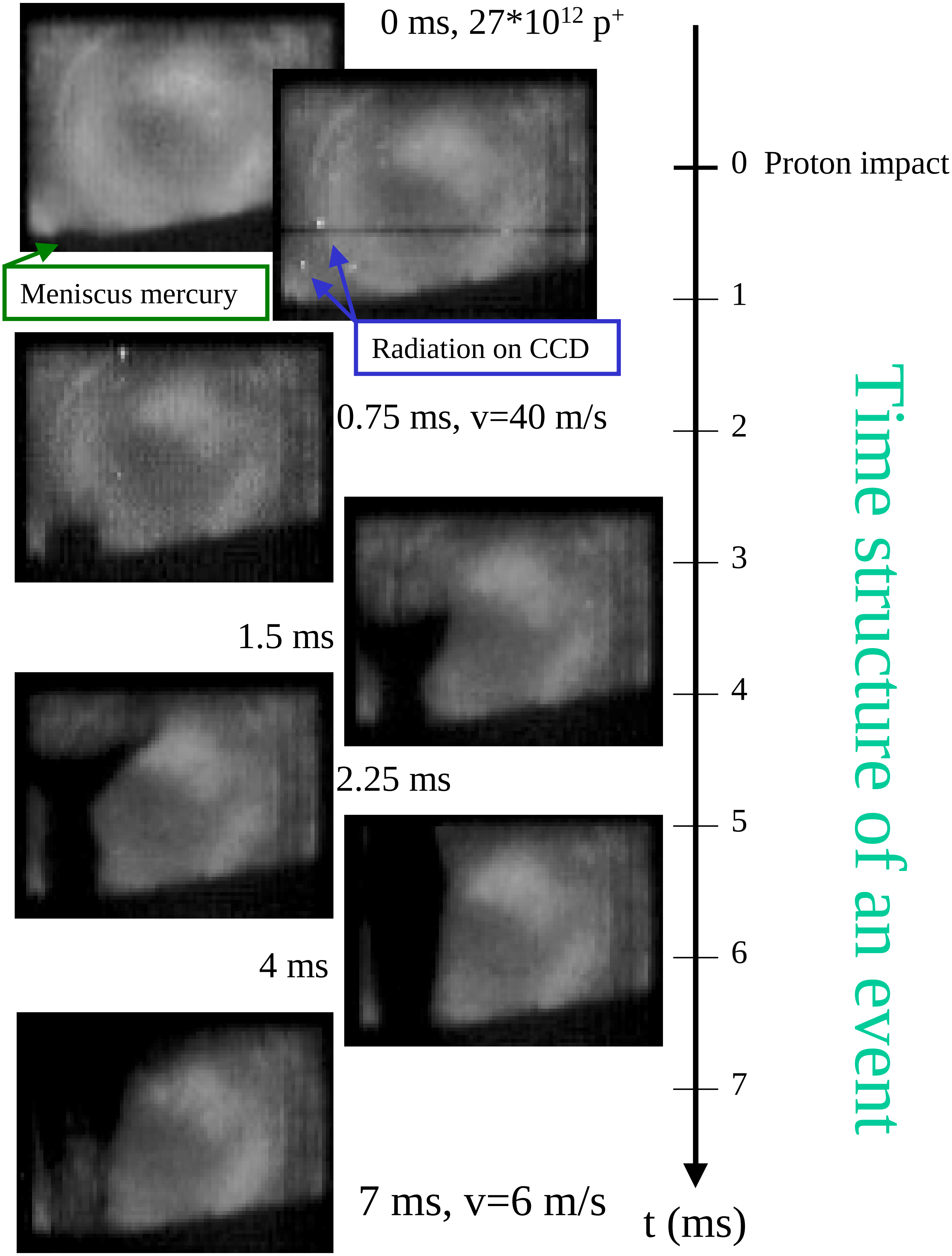
TROUGH

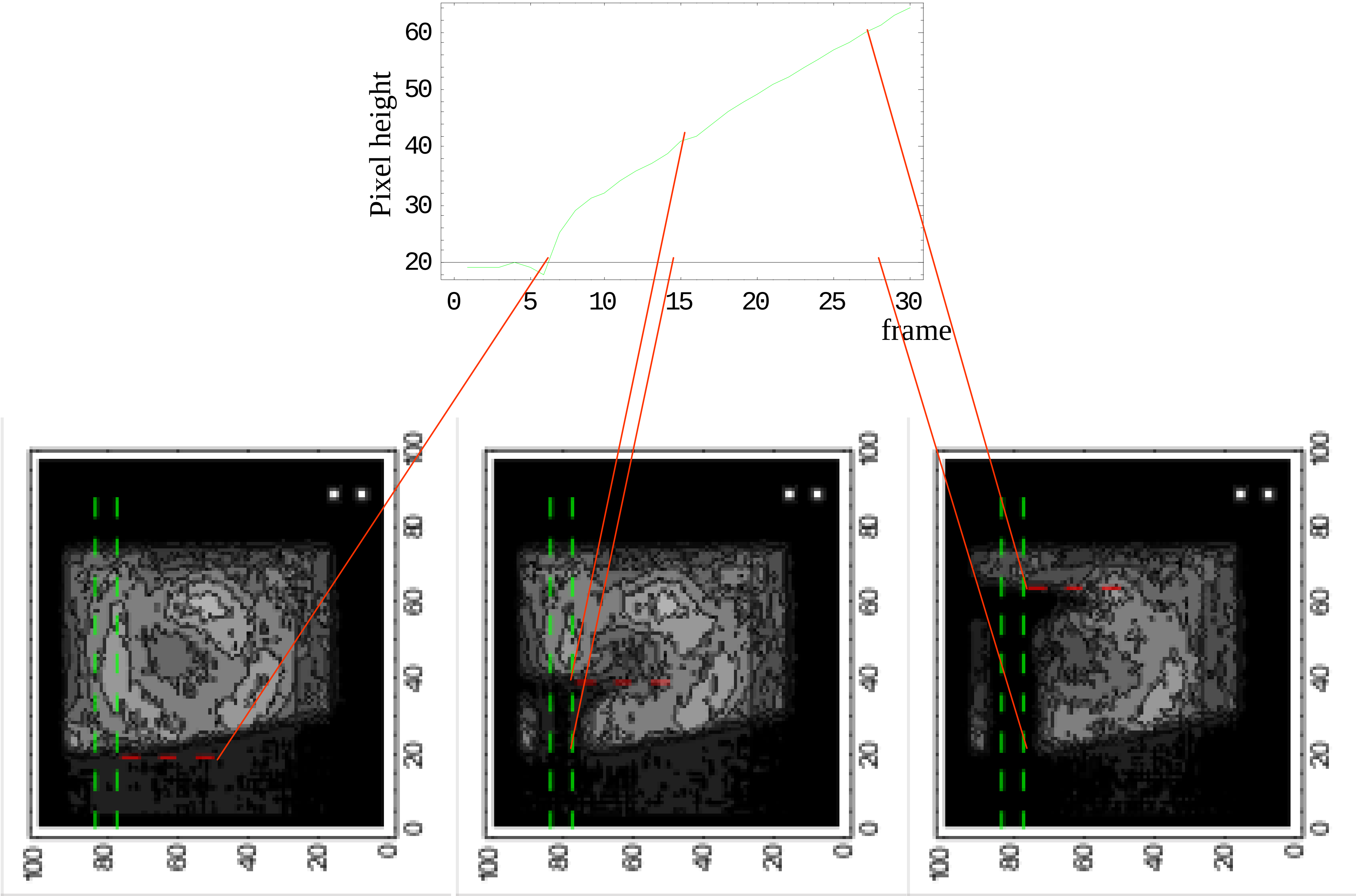


$8\ cm^3$ mercury

Length (beam axis) 60 mm

Diameter 12 mm


0 ms, 27*10^12 p^+
Meniscus mercury
Radiation on CCD
0.75 ms, v=40 m/s
1.5 ms
2.25 ms
4 ms
7 ms, v=6 m/s
0 Proton impact
1
2
3
4
5
6
7
t (ms)
Time structure of an event


Pixel height
60
50
40
30
20
0
5
10
15
20
25
30
frame

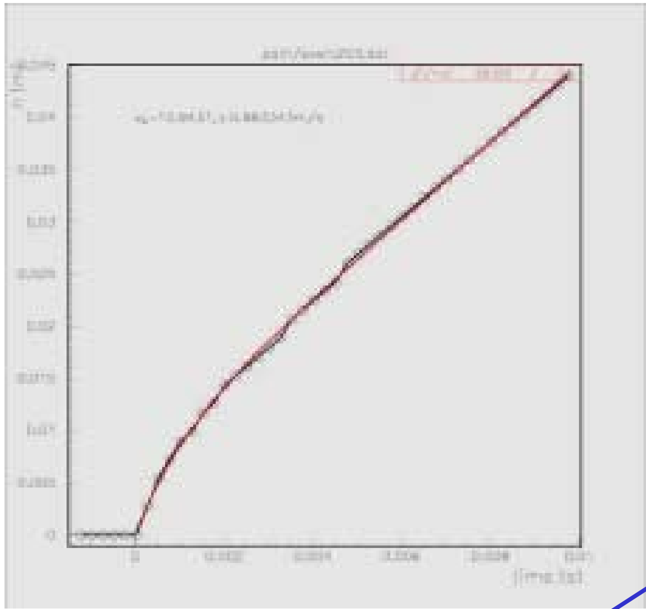
Explosion Velocity

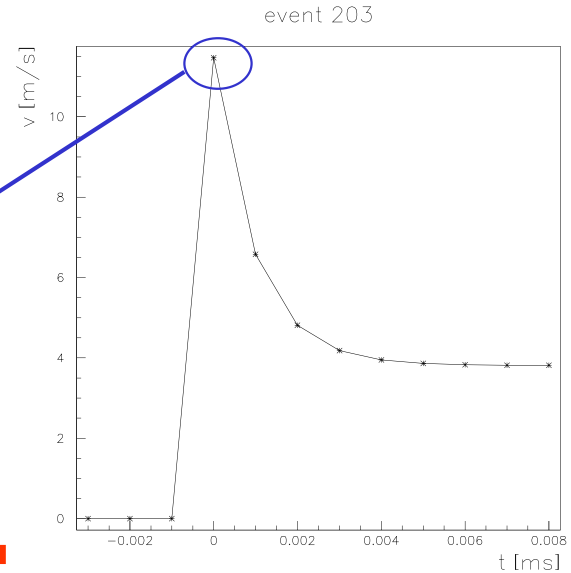
Initial velocity

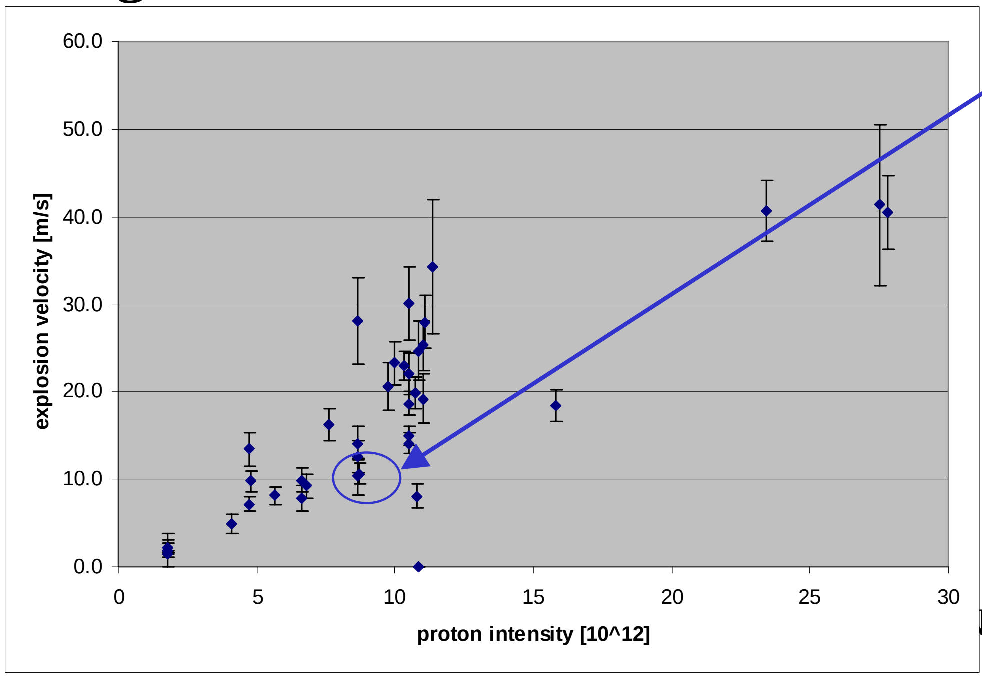
-gravity

-drag force
(Argon 1 bar)

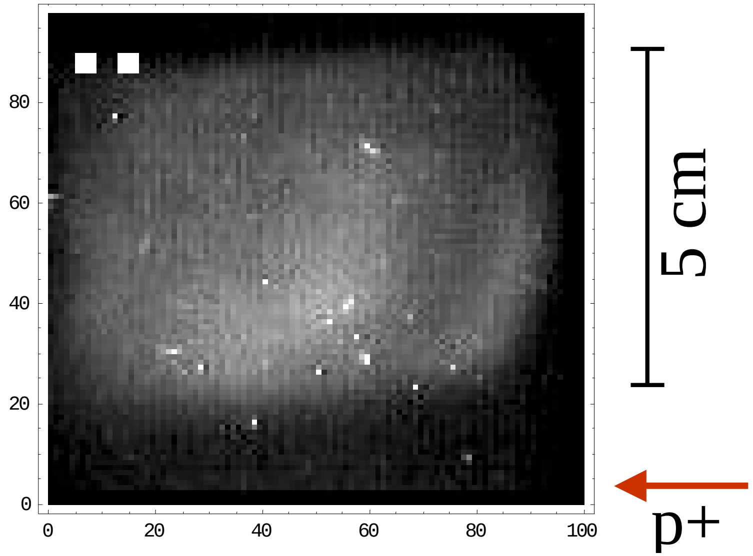
-surface tension
neglected

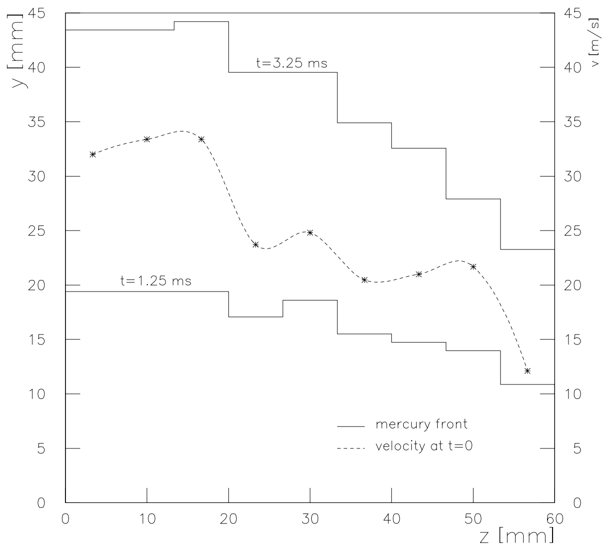


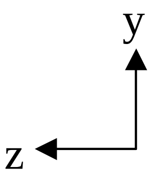


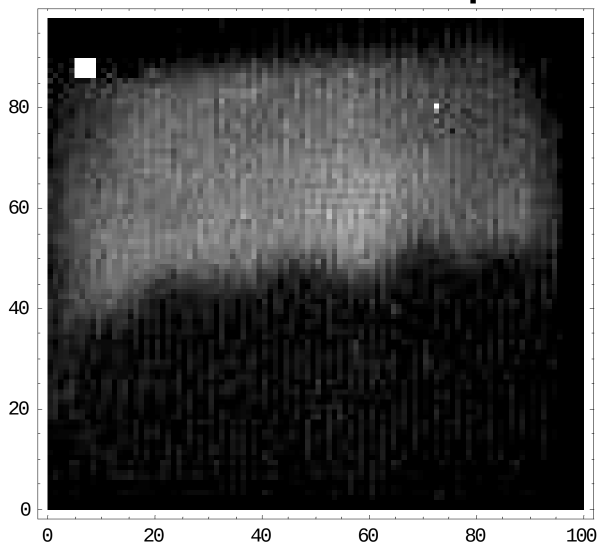


Trough Event

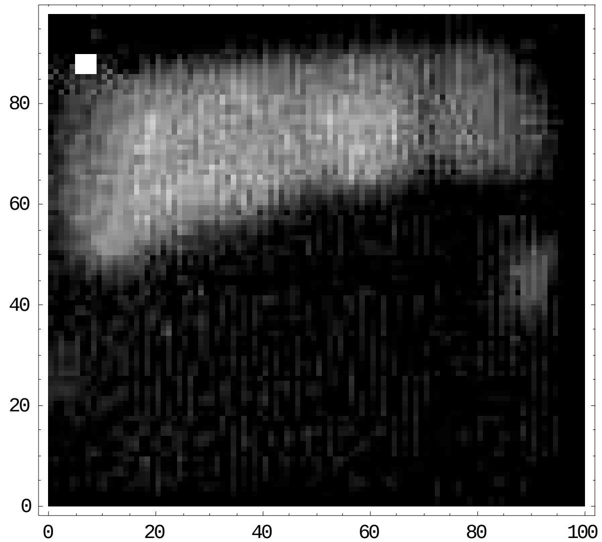


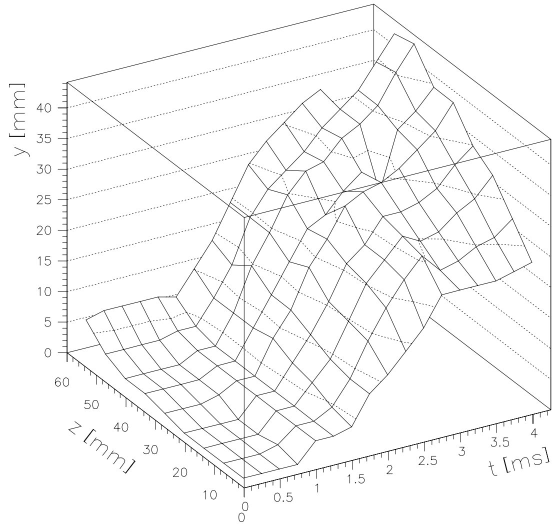






After a few milliseconds





Average mercury curtain thickness below 0.25 mm

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Protons vs. Mercury

1.4 GeV proton beam

ISOLDE GPS, Aug. 2001

40 single pulse events on thimble

ISOLDE GPS, April 2002

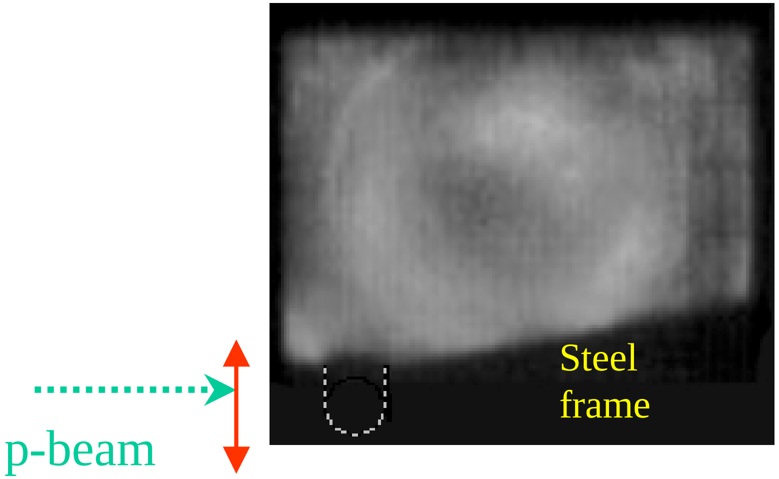
24 single pulse events on trough

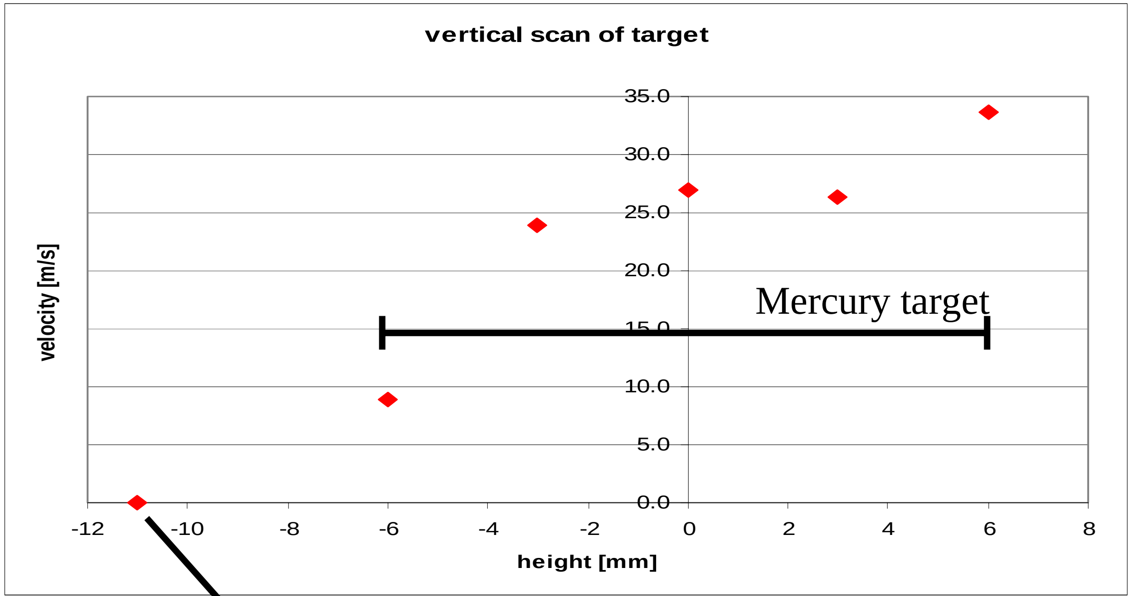
PSB (NuFACT CERN)

- pulse intensity
  1-33 10^{12} p^+ (230 10^{12} p+)
- pulse length
  0.6-19 μs (3.2 μs)
- height scan
- spot size (Gaussian)
  σ=1.2-4.1 mm (4 mm)
- Average beam density
  0.4-1.5 TP/mm^2 (3 TP/mm^2)

Height Scan

- Assure centering of the beam





Position verified with

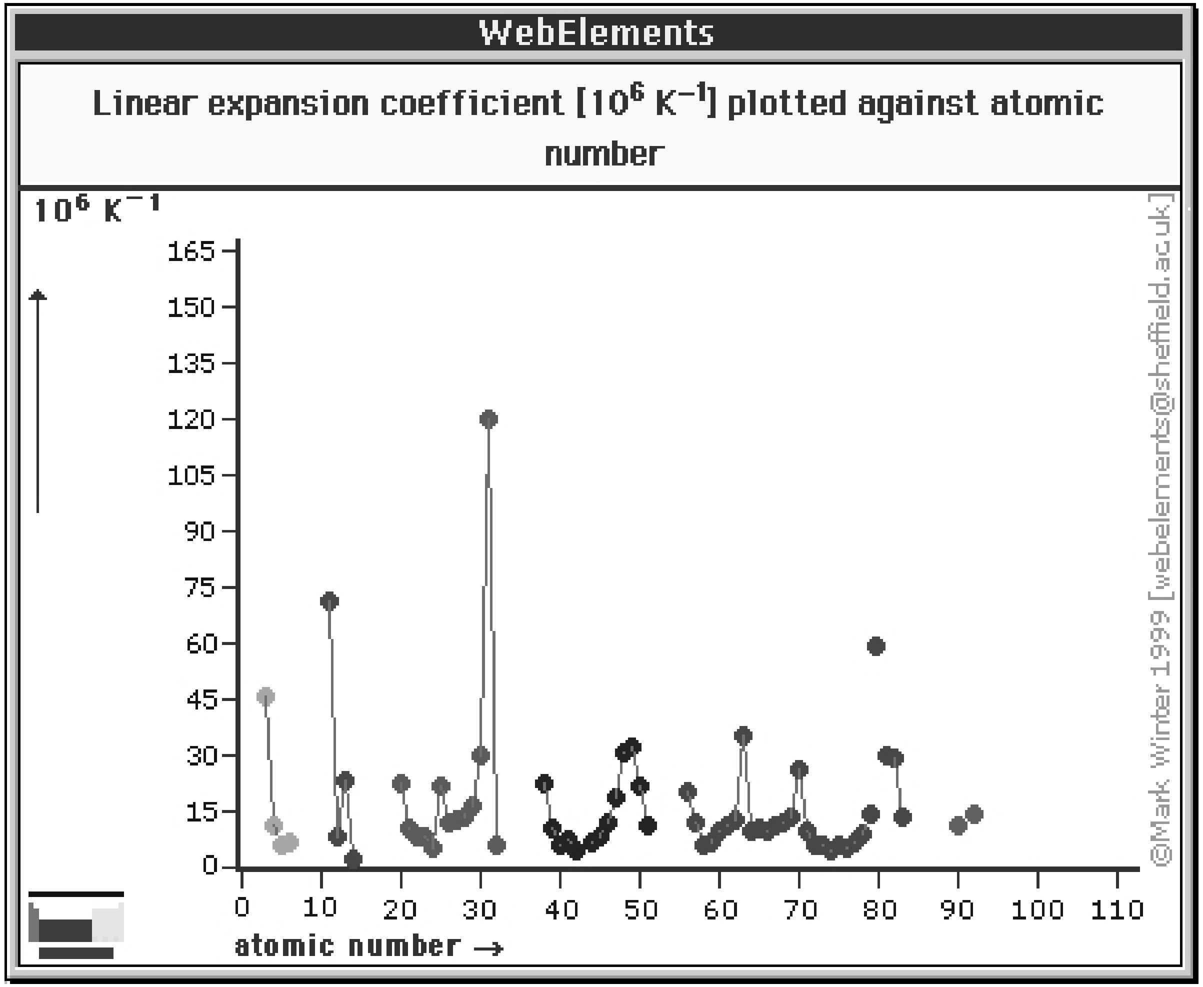
1. SEM grid
2. aluminum foil
3. beam scan on target

- beam centered
- slight offset causes minor effect

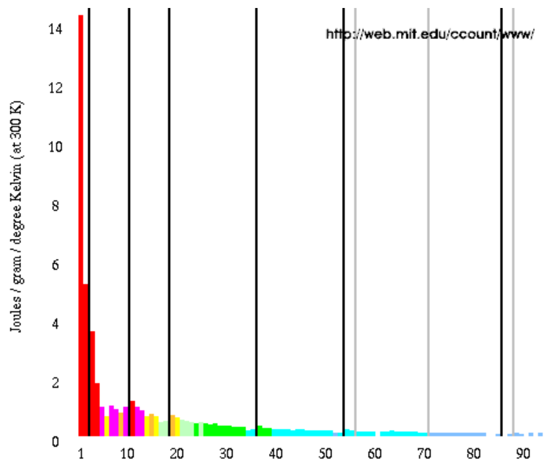
Heat capacity and linear expansion coefficient of mercury and steel much different ⇒ results in a factor 6 less effect in steel for the same proton intensity (neglecting other effects like impedance)

See also slide ‘Target Material Properties’

Target Material Properties



Despite all other advantages, ^{80}Hg is one of the elements with very high thermal expansion coefficient



Not all elements indicated

heat capacity [J/kg K]

Steel	450
Hg	140

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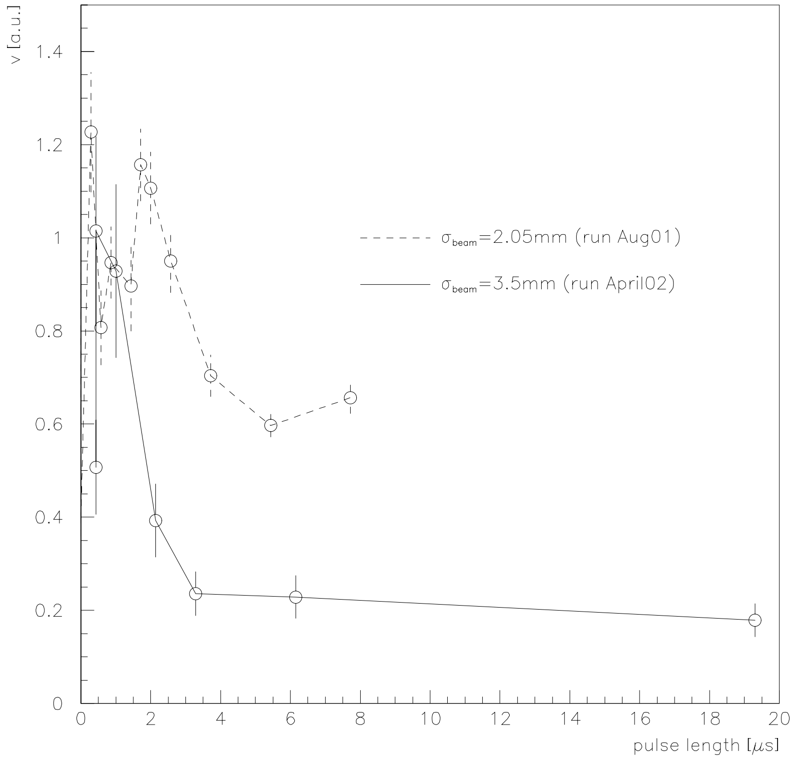
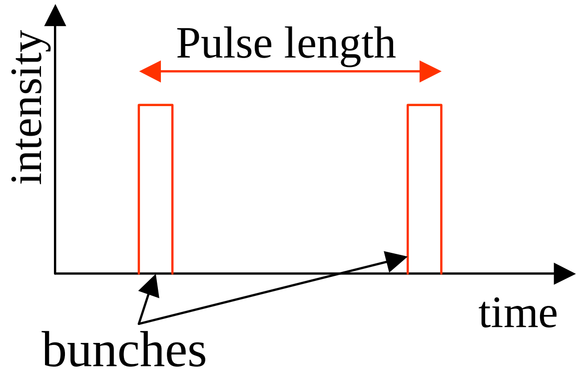
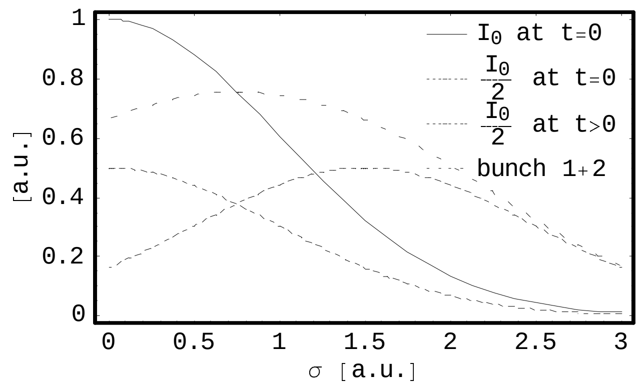
Pulse length







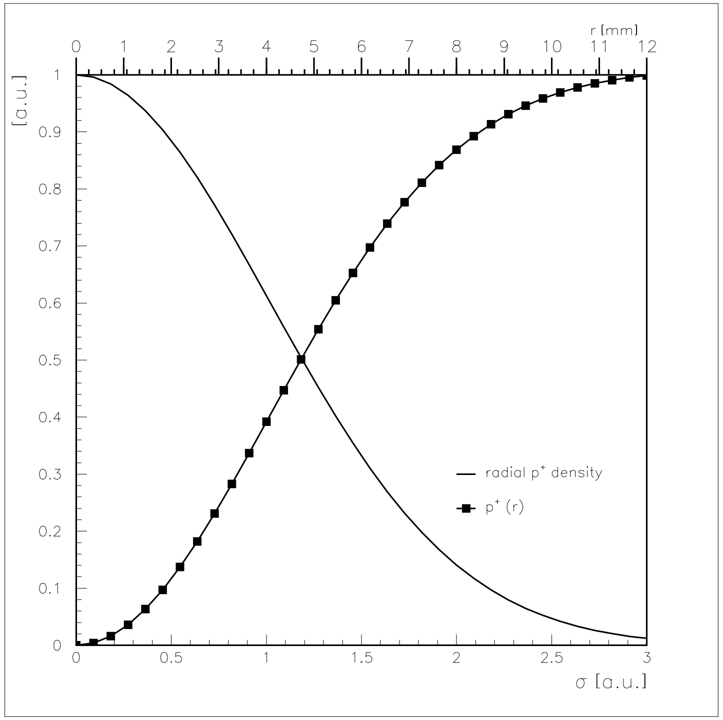
dv/dt=-dP/dr

- velocity drops for pulse length > 3 μs
- due to traveling pressure wave $\longrightarrow$
- can not be due to cavitation as …

Cavitation

- cavitation might occur
  → reduced interaction length

- assuming cavitation in center
  → low percentage of particle interaction lost



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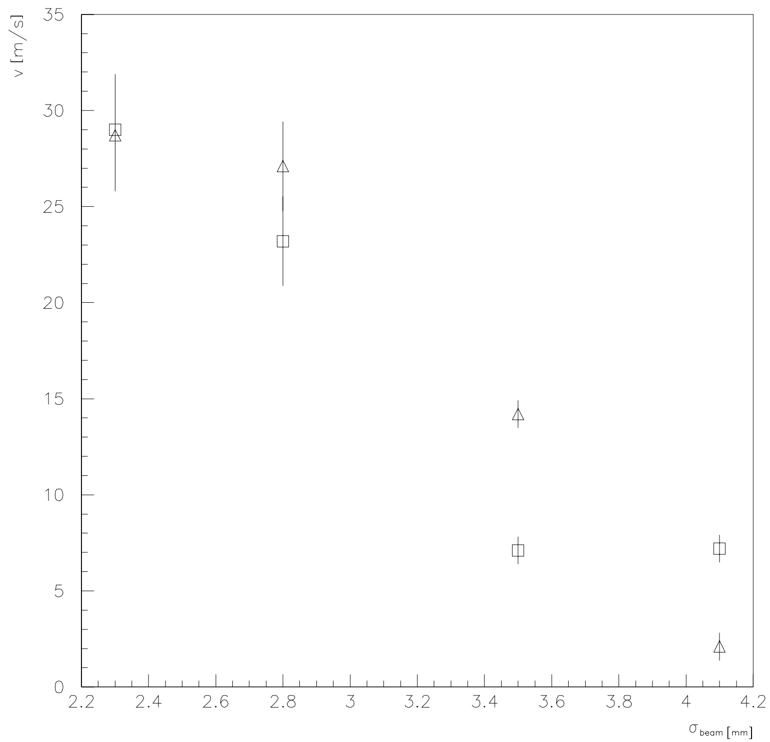
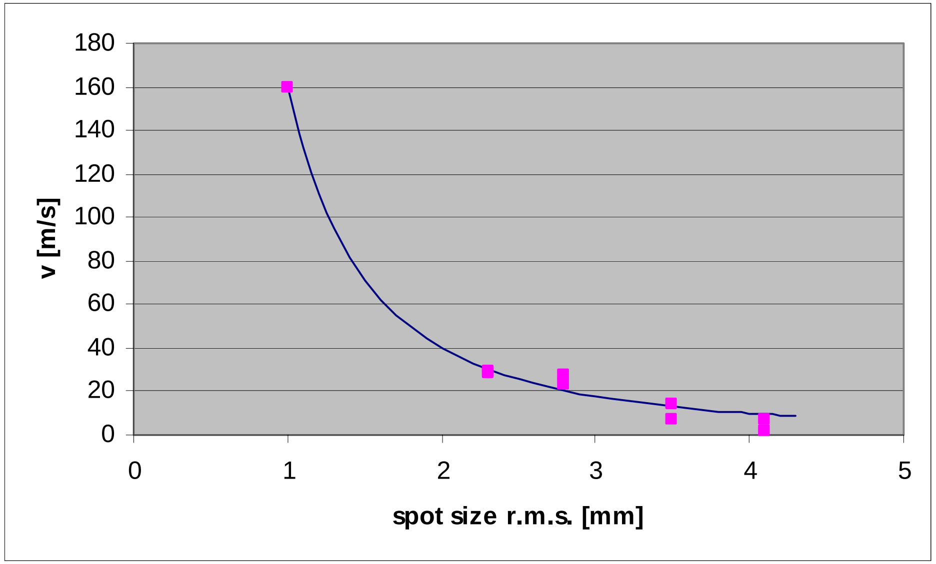
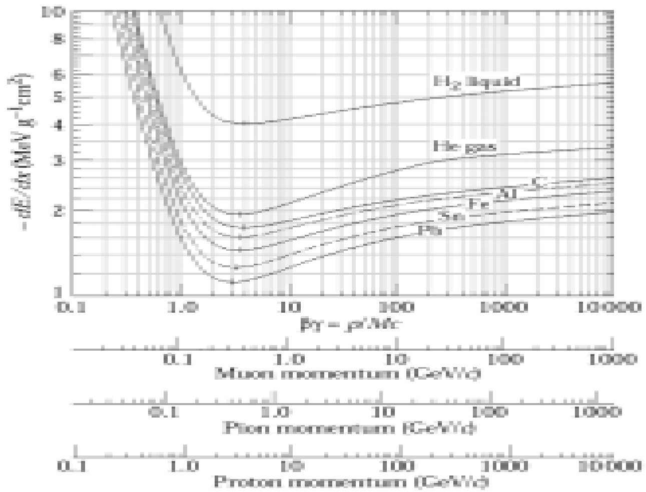
Spot size







17 TP corresponding BNL event:

σ≈1mm, v≈160m/s

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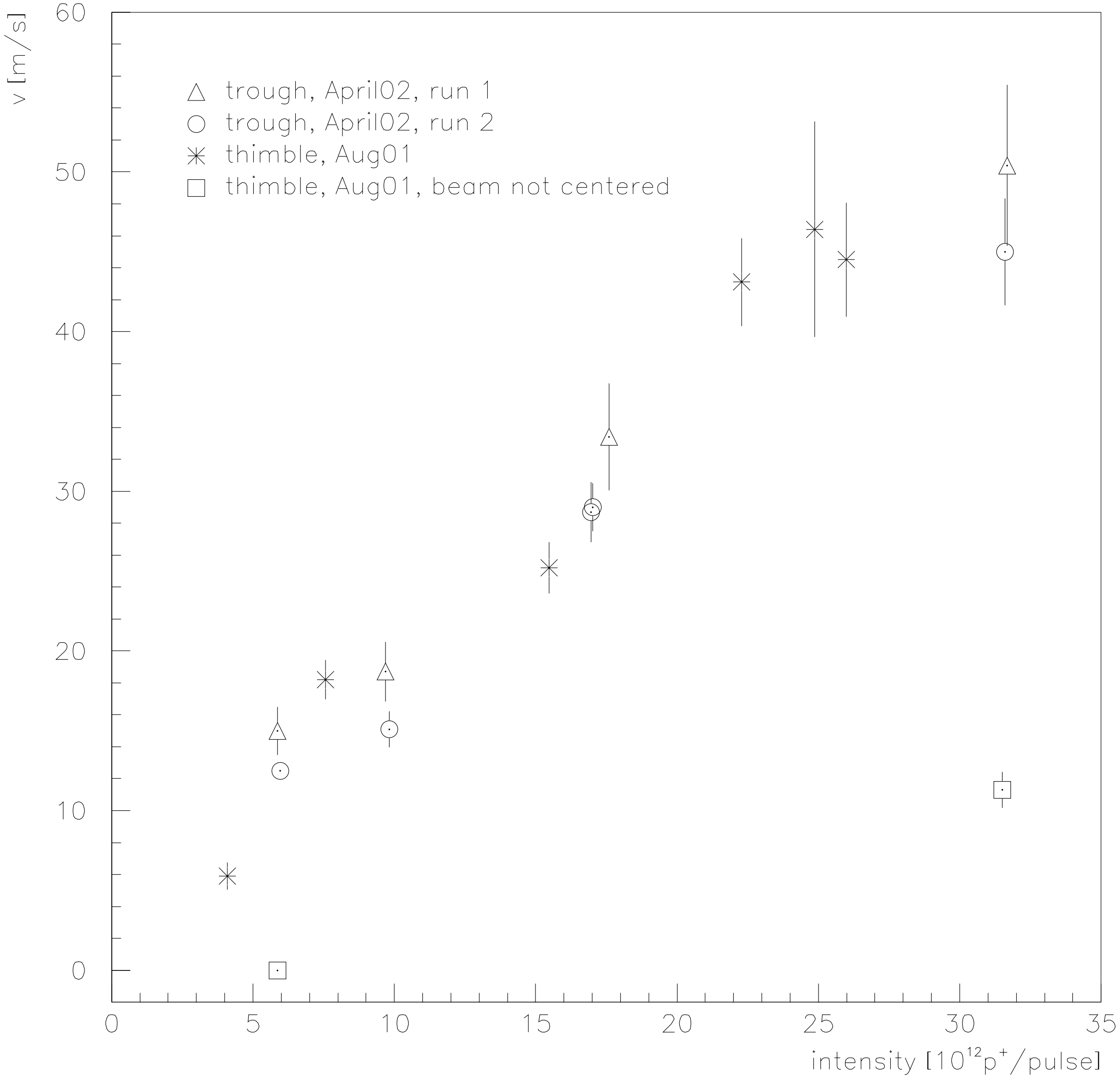
Scaling
Intensity



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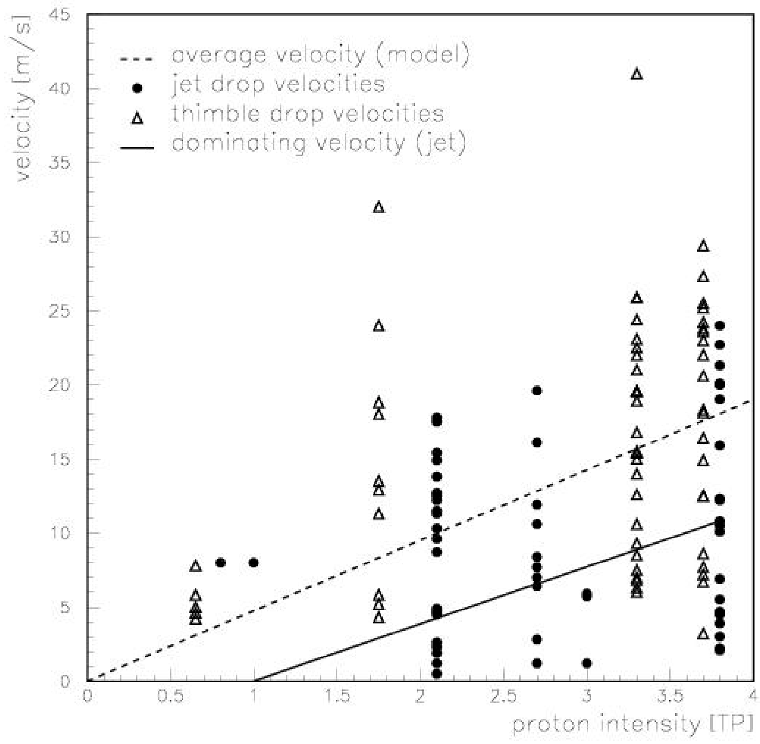
Trough ↔ Jet

BNL events showed:

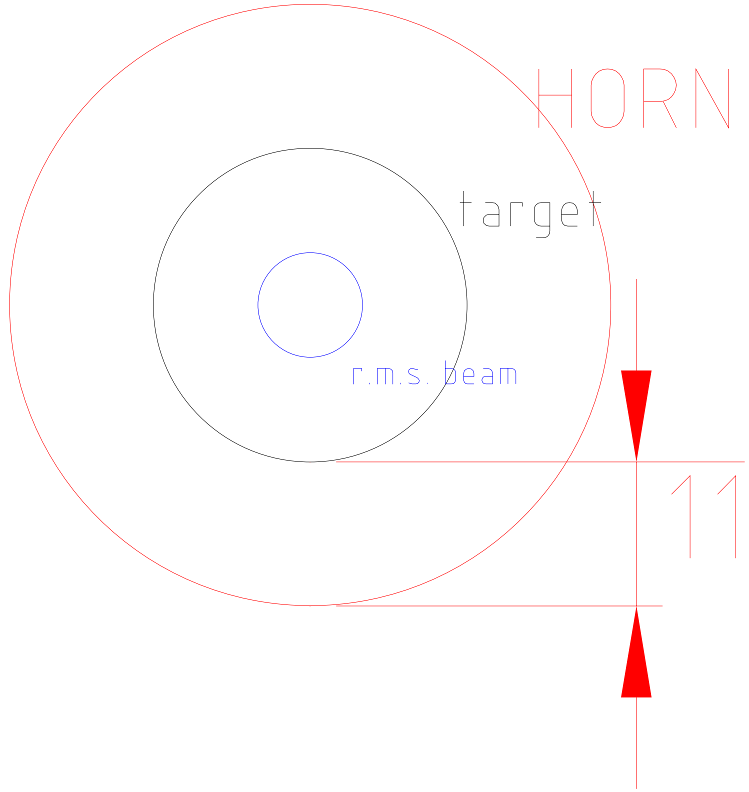
- explosion velocities of thimble 2 times higher than jet
  - due to free surface



TARGET STATION PARAMETERS

- Diameter horn = 46 mm
- 5 σ beam ≤ horn radius

$\Rightarrow \sigma_{beam} = 4$ mm



S. Gilardoni

- r_{target}=3 σ beam

$\Rightarrow d_{target} = 24$ mm

Scaling to ν-Factory

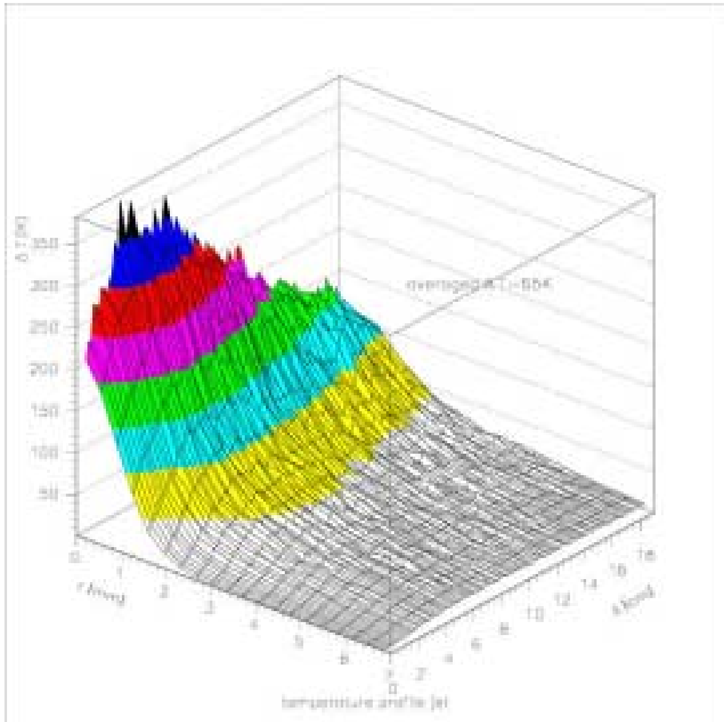
- For maximum intensity at ISOLDE: v=50 m/s
- for ν-Factory (CERN):
    - intensity 7 times higher
    - spot size 2 times larger (4 mm)
    - trough→jet: factor 0.5
    - jet under vacuum removes drag forces
    - pulse length: 3.2 μs → sound travels 5 mm
    - Proton energy from 1.4 GeV to 2.2 GeV: gain 0.7

⇒ Explosion velocities about 2*jet speed → 4π-explosion

4π-explosion not acceptable

- Where we can gain?
  - spot size fixed (horn dimensions)
  - 2.2 GeV: already at minimum dE/dx
  - Pulse length to an order of 100μs "solves everything"
  - Mercury 'worst' element we could use

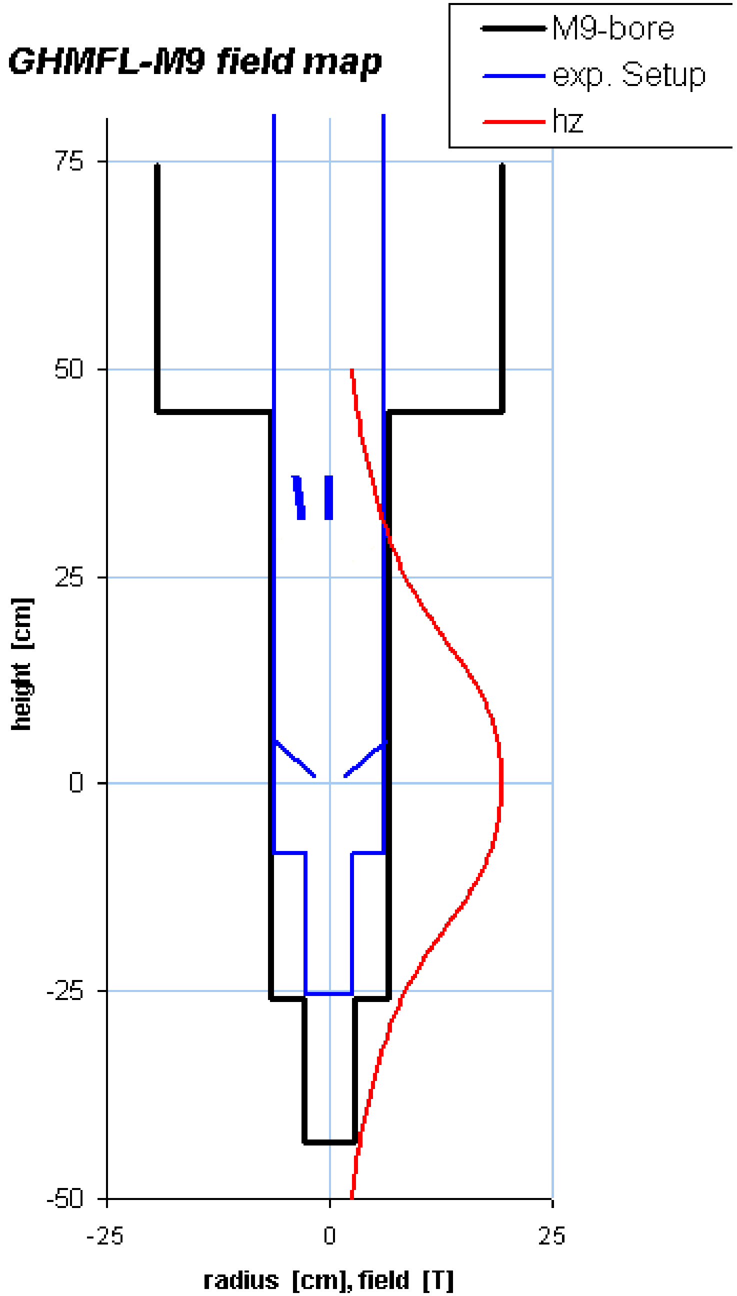
    ➢ These velocities occur only in small part of the target
  - invert jet direction
  - Remember: velocities given are v(t=0)



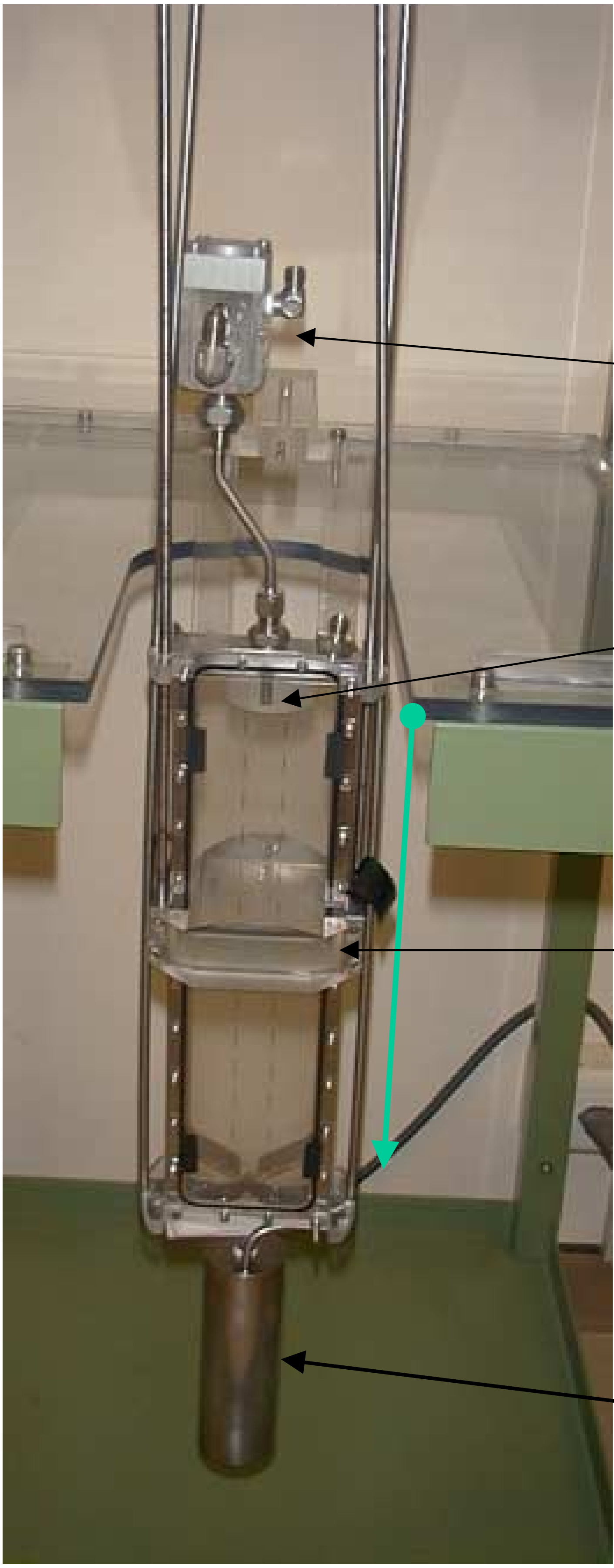
Magneto HydroDynamics

Liquid metal Jet in a high magnetic field

- Grenoble High Magnetic Field
- Vertical Solenoid, B_{max}=13/20 T
- Mercury jet:
  - **v_{max}=15 m/s**
  - **d=4mm**
  - Collinear and inclined to 6°
- Optical read-out:
  - High speed camera
  - ≤ 8000 frames/s



Inner Setup



Pneumatic valve

Nozzle d=4mm

Drift length$_{max}$ l=27 cm

Moveable mirror system

Mercury reservoir

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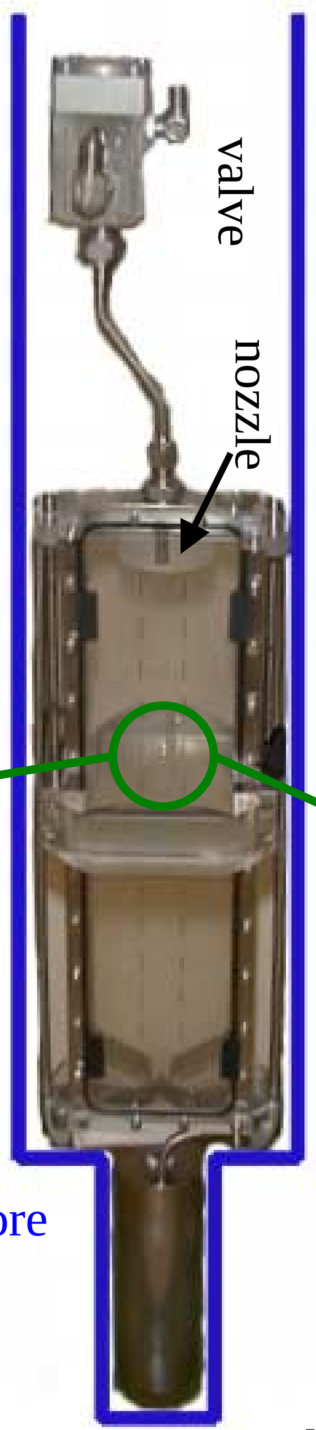
π-collection via a 20 T solenoid

(US-scheme)

Magneto-Hydro-Dynamics

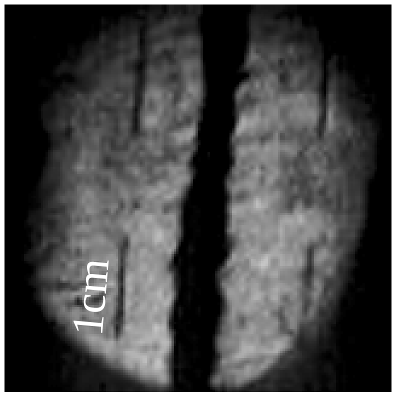
GHMFL Grenoble



Observed MHD effects in the supply piping and free jet:

Mercury jet (v=15 m/s)

B=0 T



B=18 T

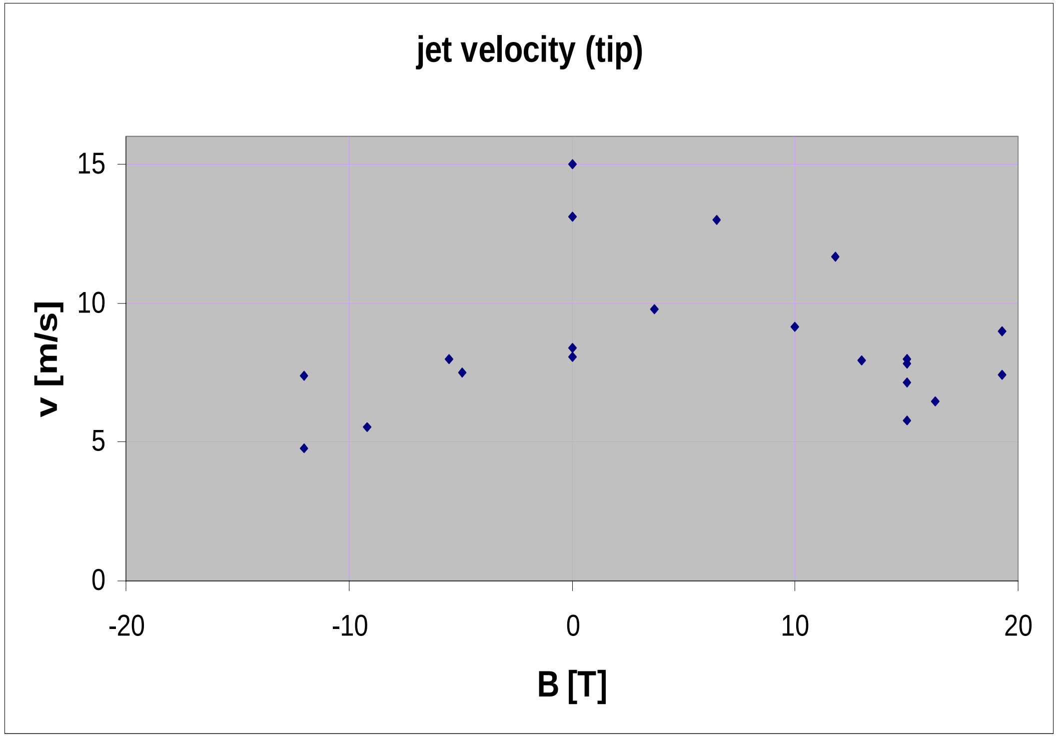
- Jet deflection

- Reduction of the jet velocity

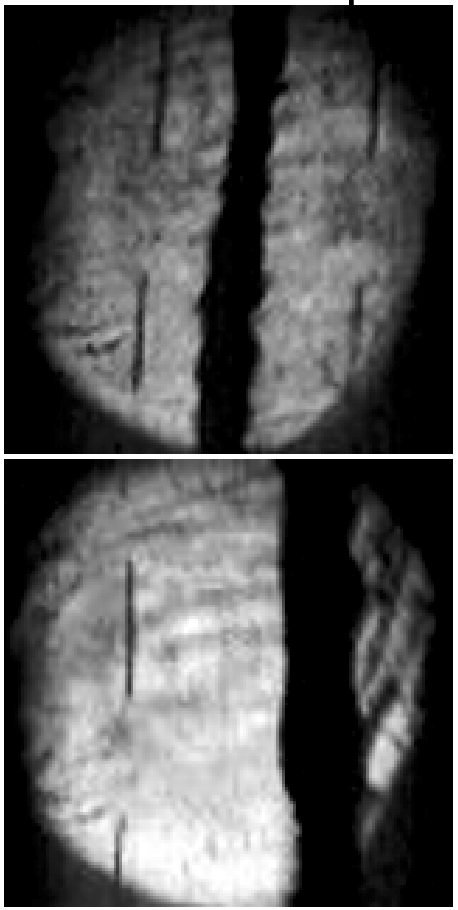
March & September 2001

First observations

- Displacement of the jet
- Velocity decrease
- All observations are qualitative!



B=0



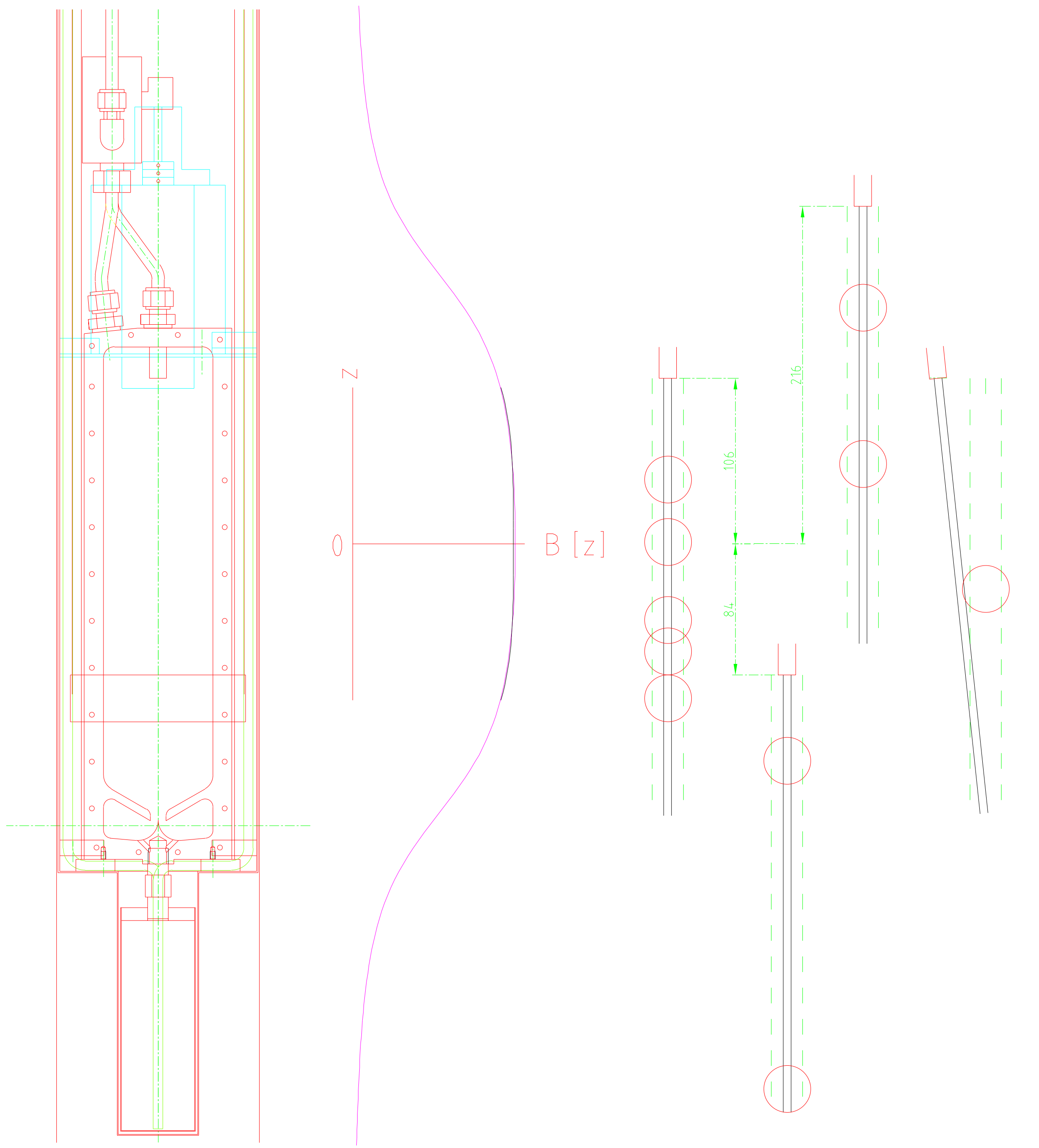
Recorded at 6.5 cm from nozzle

B=16 T

Caused by?

• MHD in pipe system and/or of free jet?

13-TESLA SETUP



Indicated:

- mechanical setup
  - 0°/6 ° nozzle
- B-Field
- jet & image positions for all events

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Events March 2002

13 Tesla setup

- never impossible to inject a jet in(to) the magnetic field
- jet surface smoothed in high magnetic field
- no deflection of jet at 6° nozzle
- camera resolution <0.5 mm, time resolution 25μs

- main problem: establishing a ‘good’ jet

MHD summary

- 13 Tesla setup:
  - No ‘frightening’ effects
  - smoothing of jet surface
- 20 Tesla setup:
  - Observation of deflection/velocity reduction
- **MORE EFFORT on ESTABLISHING A JET**
  - pressure supply system
  - **nozzle design**
  - Collaboration with EPFL Lausanne

For your information/ advertisement

• Possible sites for further studies:

•ISOLDE:

superb location for studies on proton induced shocks for all kinds of targets

•GHMFL:

Within next two years a 17 Tesla-40 cm bore magnet is constructed.

Last Slide

- No further tests in ISOLDE for 2002
  - Knowledge is sufficient to extrapolate behavior of jet target in proton beam and to benchmark codes.
  - compare directly with codes

- (last) run at GHMFL in June ’02
  - 20-Tesla solenoid
  - 6 ° nozzle only